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Structural Safety Studies of Kahir Dam in Iran

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Abstract: In this paper, structural safety study of Kahir dam in Iran was carried out. The 3D finite element method was used to analyze the deformations and stresses in dam body and the impervious face of the dam. Anisotropic thin element is adopted to simulate the contact between dam body and the impervious face. Results show that the symmetrical trapezoid shaped hard fill dam has advantages of high safety. Also, comparing to gravity dam section, the characteristics and the distribution laws of the deformations and stresses in Kahir dam body and its impervious face are concluded. According to findings, the safety of the dam is overall evaluated. It is clear from results that the hard fill dam has greater safety than gravity dam.

Key words: Structural · Kahir dam · Finite element method · Impervious face

INTRODUCTION

Parametric studies on materials and safety of dams were done in different parts of the world [1, 2]. The concept of hard fill is not new. In other guises it can be termed soil cement sand and Cement Sand Gravel (CSG). The use of soil cement for upstream wave protection on embankment dams was pioneered by the USBR on the bonny reservoir in Colorado, USA, in 1951 [2]. A trapezoidal CSG dam is a new type of a dam that combines a trapezoidal dam and CSG materials. The maximum compressive stress in a trapezoidal concrete gravity dam is relatively low compared with other concrete dams. This means that a trapezoidal concrete dam can utilize even CSG as its dam body material [3]. According to preceding findings, slope stability analysis gave a minimum safety factor of 1.31 and 1.22 using effective stress analysis (ESA) and effective stress analysis (USA) methods, respectively [4, 5]. In addition, there are further studies on the safety of symmetrical hard fill dams and findings indicate that the hard fill dam has greater safety than gravity dam [6]. The concept of the faced symmetrical hard fill dam, or trapezoidal CSG dam as it is termed in Japan, is explored more fully in ICOLD Bulletin 117 [7].

The Kahir dam will be the first faced symmetrical hard fill dam to be constructed in Southeast Iran. Kahir is 53 m high, 370 m long at the crest and contain approximately 510000 m^3 of concrete. It is a symmetrical trapezoid shaped dam with a concrete impervious face in the upstream [6].

Considerable safety of hydro structures such as dams [8, 9] adds the study of risky. In this paper, structural safety study of Kahir dam in Iran was carried out. The 3D finite element model was used to analyze the deformations and stresses in dam body and the impervious face of the dam. And also, anisotropic thin elements were adopted to simulate the contact between dam body and the impervious face.

Features of Kahir Hard Fill Dam: Hard fill is a material made by adding little cement to rock like material such as riverbed gravel or excavation muck. Figure 1 shows the upstream view and typical profile and of Kahir dam, which is symmetrical trapezoid shaped or approximately symmetrical.

Fem Analysis: Three dimensional FEM analysis status was conducted for static analysis. The height of the Kahir hard fill dam is 53m and the crest width is 4m with the slope 0.7H:1V. The thickness of the facing was adopted by equation (1)

$$t=0.3+0.00235H \text{ (m)} \quad (1)$$

Where, H is the distance from the crest of the dam [10]. The calculation domain of foundation extends by 1 times the height of the dam in the upstream and downstream and the boundaries of the foundation are all constrained normally.

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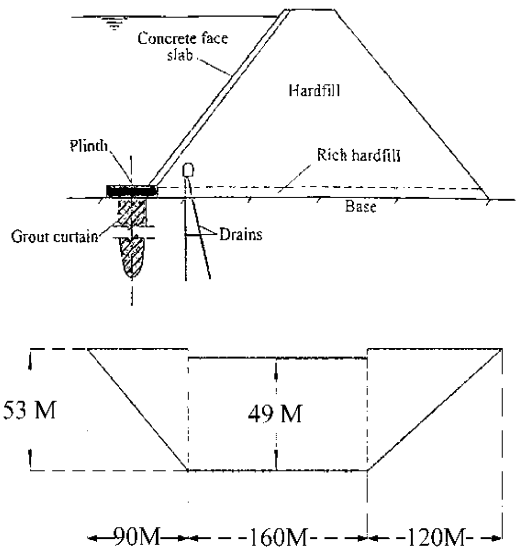

Fig. 1: Typical cross section and upstream view

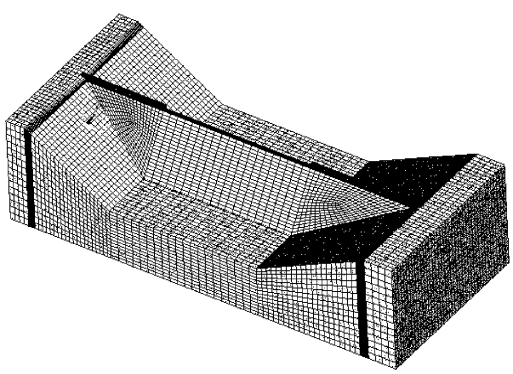

Fig. 2: FiniteElement Model

Anisotropic thin elements were adopted to simulate the contact between the face and dam body. The 3D FEM model is shown in Fig. 2. In static analysis, the loads contain deadweight of the dam, water pressure on the upstream face and the foundation uplift pressure.

Facing concrete, hard fill and foundation are assumed as elastic material. In this study, material properties were assumed as the constant values shown in Table 1.

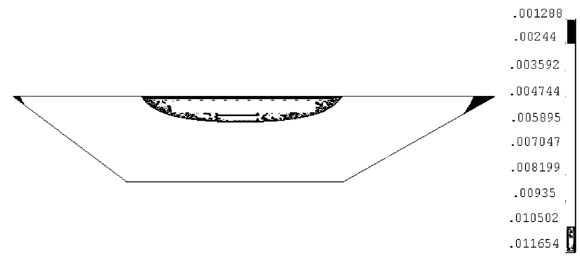

Fig. 3: Distribution on deflection at facing (m)

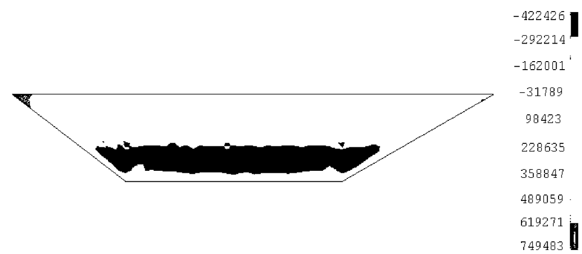

Fig. 4: Principal stress distribution at facing σ_1 (Pa)

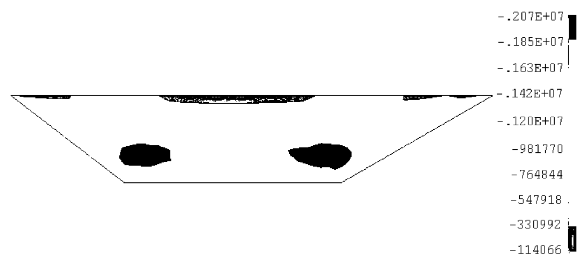

Fig. 5: Principal stress distribution at facing σ_3 (Pa)

In the results, the positive value means tensile stress, the negative value means compressive stress, σ_1 signifies the first principal stress on the tensile side and σ_3 Signifies the third principal stress on the compressive side.

Stress and Deformation Behavior of the Facing: Fig. 3, Fig. 4, Fig. 5 and Table 2 show the deformations and stresses distribution at facing. Comparing with the CFRD, deformation at facing of Kahir hard fill dam is much smaller (maximum deformation at facing of CFRD dam is about 100 mm [10]).

Table 1: Materials properties

	Trapezoid shaped dam			Gravity dam (Triangle dam)	
	Concrete	Hard fill	Foundation	Dam body	Foundation
Modulus of elasticity (GPa)	28	5	3	24	11
Poisson's ratio	0.167	0.25	0.30	0.20	0.30
Unit mass (kg/m^3)	2400	2200	----	2400	---

Table 2: Maximum stress on facing

Item	Dam face	Maximum strength	Safety factor
σ_1	0.75 (MPa)	2.5 (MPa)	3
σ_3	-2 (MPa)	-25 (MPa)	12.5

Fig. 6: Principal stress distribution on dam body σ_1 in trap.ezoid shaped dam (Pa)

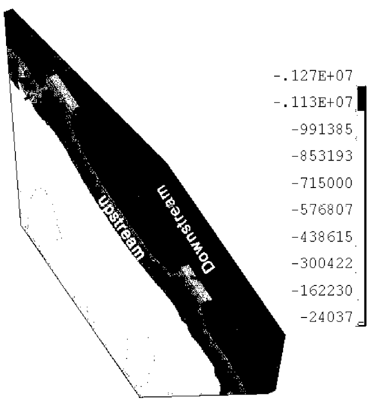

Fig. 7: Principal stress distribution on dam body σ_3 in trapezoid shaped dam (Pa)

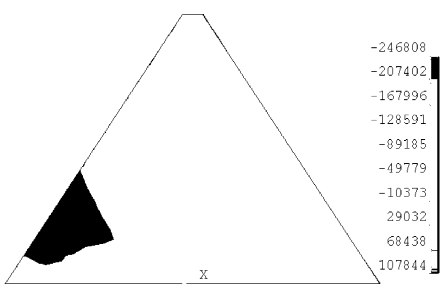

Fig. 8: Principal stress distribution σ_1 in trapezoid shaped dam (Pa)

The stresses distribution at facing is also great improved. The maximum principal tensile stress and the maximum principal compressive stress at facing is about 0.75 and -2 MPa. While, the maximum tensile strength and the maximum compressive strength of upstream face material is about 2.5 and -25 Mpa. From the results, because the deformation modulus of hard fill is greater than that of rock fill [10], the deformations are much smaller. As results show, the facing safety has great improved.

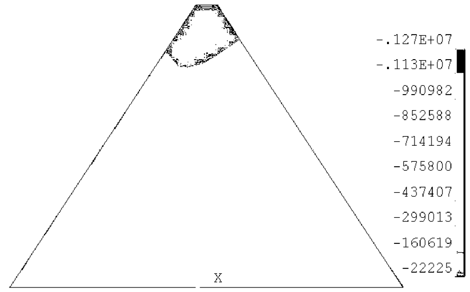

Fig. 9: Principal stress distribution σ_3 in trapezoid shaped dam (Pa)

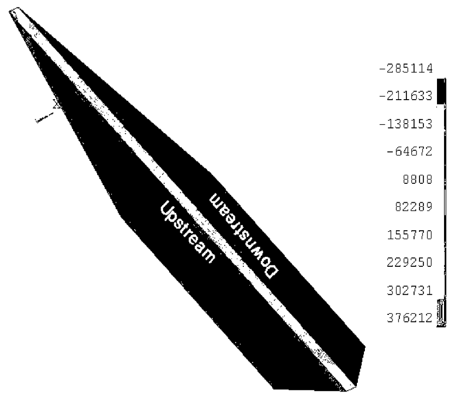

Fig. 10: Principal stress distribution σ_1 in triangle shaped dam (Pa)

Stress and Deformation Behavior of the Dam: Fig. 6, Fig. 7, Fig. 8 and Fig. 9 show the maximum and minimum principal stress distribution on dam body (3D) and on typical profile of dam body located on spillway axis of the dam. Also, Fig. 10 and Fig. 11 show these results in a triangular shaped (gravity) dam. In the σ_1 case in the trapezoid shaped dam, the dominant stress was 0.2 MPa, revealing that would not develop considerable tensile stress. In the σ_3 case, the dominant stress was -1.27 MPa, revealing that smaller stress is generated in contrast to gravity dam. While, the σ_1 value in triangle shape is equal to 0.38 MPa and the σ_3 value is equal to -1.85 MPa. According to T.hirose's finding [3], it is possible to achieve a 5 MPa compressive strength and 0.6 MPa tensile strength with a cement content of around 50kg/m^3. It is not only possible to use the low strength hard fill as a construction material for the Kahir trapezoid shaped dam, but also gets a high level of safety.

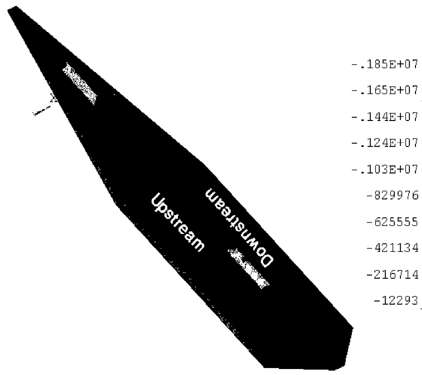

Fig. 11: Principal stress distribution σ_3 in triangle shaped dam (Pa)

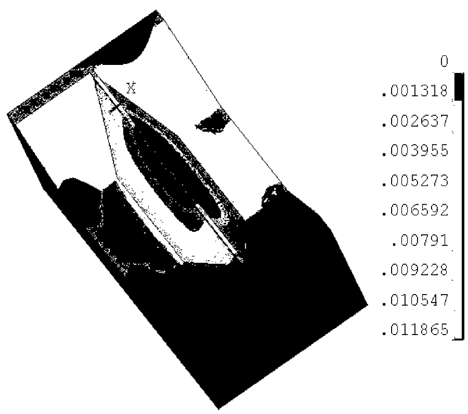

Fig. 12: Distribution on deflection at dam body of Kahir dam (m)

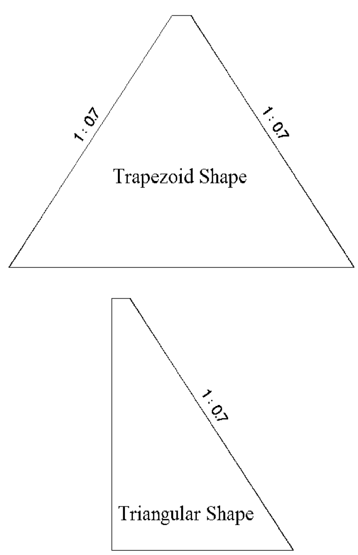

Fig. 13: Shape of dam models

Fig. 13 shows the deformation of the Kahir dam in 3D model. Maximum deformation of the dam, which occurs in dam crest, is about 12 mm.

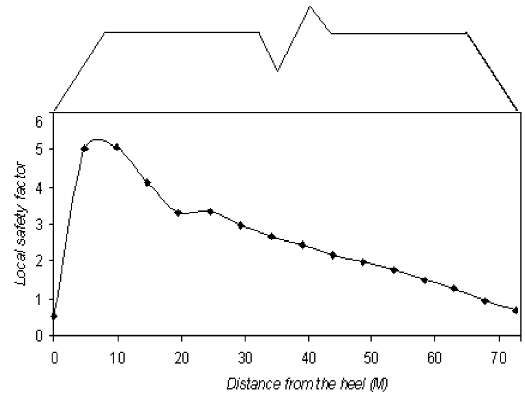

Fig. 14: Distribution on local safety factor against sliding at basement of the Kahir dam

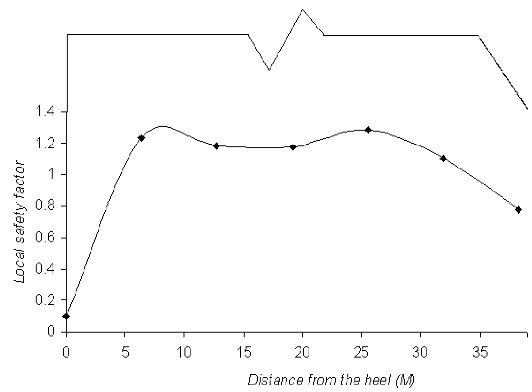

Fig. 15: Distribution on local safety factor against sliding at basement of the triangular shaped dam

Stability Analysis of Dam Foundation: Local safety factor against sliding at basement of dam can be derived using Eq. 2 [10].

$$k = \frac{\sigma * f + C}{\tau} \quad (2)$$

Where, σ is normal stress in vertical direction at basement of dam, τ is shear stress at basement of dam, *f* is friction against shearing and C is cohesion against shearing.

Safety factors against sliding at basement of dam can be derived using Eq. 3 [10].

$$K = \frac{\sum \sigma * f + CA}{\sum \tau} \quad (3)$$

Where, *A* is the width of the dam basement.

From the viewpoint of structural stability, the symmetrical trapezoid shaped hard fill dam should have great safety against sliding. Fig. 13 shows the shapes of these two types of dams.

Table 3: Safety factors against sliding

Shape	Safety factors against sliding K
Triangular shape	1
Trapezoid shape (Kahir dam)	1.8

Also, Fig. 14 shows the distribution on local safety factor against sliding at the basement of Kahir dam and Fig. 15 shows the distribution on local safety factor against sliding at basement of the triangle shaped dam. In this study, *f* an C were assumed as constant values 0.53 and 0.15, respectively. The safety factor against sliding is shown in Table 3.

According to the safety factor results, the Kahir hard fill dam has great safety against sliding. Results show that the high shear strength of dam foundation is not required in order to satisfy the safety against sliding. As a result, the Kahir trapezoid shaped dam can be constructed even on the poor foundation.

CONCLUSION

In this paper, safety study of the Kahir dam was carried out. The 3D FEM model was used to analyze the deformations and stresses in dam body and the impervious face. There are some conclusions in the following:

- From the results, the deformations and tensile stress are small at Kahir dam facing. So, facing safety has great improved.
- The unconfined compressive strength is the most important requirement for Kahir dam.
- The safety against sliding of Kahir dam is about twice as many as the conventional gravity dam. As a result, Kahir trapezoid shaped dam can be constructed even on poor foundations.
- The study and analysis show that Kahir hard fill dam has greater safety than gravity dam, so it's a dam with high safety.

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